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Multi-branch X-ray Split and Delay

Momentum Review of LDRD 20180684ER

PI: Dinh Nguyen

Presenter: Arianna Gleason

Aug-6-2018

Project team members

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- SLAC
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  - T. Tookey; P. Hart; M. Weaver, LCLS Detector Group
  - E. Galtier, MEC Instrument Scientist
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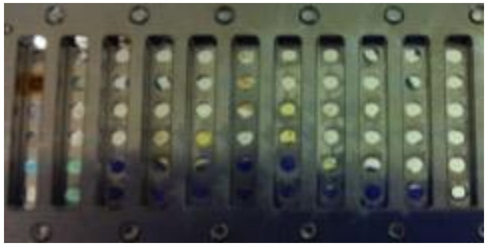
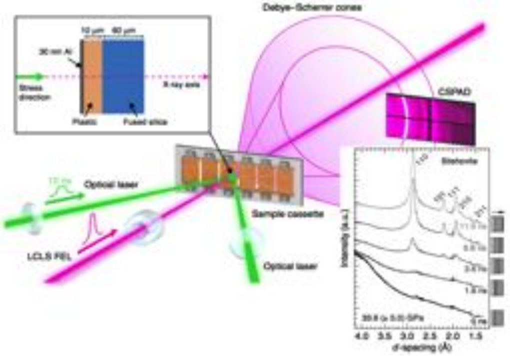
Project Overview

- Recent advancements in X-ray free electron laser (XFEL) probes coupled with high-repetition laser-driven shock waves have enabled the condensed matter physics community to begin high fidelity spatial and temporal studies on material transformations during dynamic compression → reliant on multi-target + multi-shot approach to build up kinetics information.





Gleason et al., 2015; 2017a,b

- We were not allocated LCLS beam time to perform the multi-branch X-ray split-and-delay. We received beam time at the Argonne APS which has different photon characteristics. We therefore modified the split-and-delay optics to work with the APS beams.

Overall Project Goals

- Construct an X-ray delay line using stationary Bragg reflectors optimized for future dynamic compression experiments using time-angle correlated detectors
- With allocated APS beamtime:
  – monitor photon throughput
  – develop and test timing diagnostics to establish resolution limits and time synchronization procedures
  – develop beam-center positioning and detector placement strategies to collect delayed XRD patterns at different positions

Project Deliverables FY18

- Static delay line diagnostic that can be inserted into APS hutch to perform the first single-target shock compression kinetics experiment
- test photon count optimization during APS hybrid mode for XRD
- test detector types and performance
- test decouple line broadening mechanisms in materials

Technical progress to date

-beamtime proposals submitted to LCLS and to APS

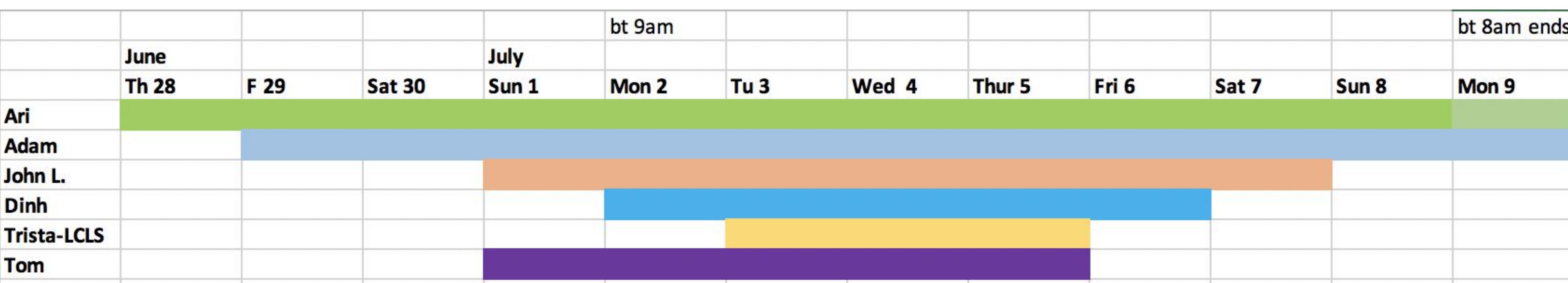
-beamtime granted at APS: HPCAT IDE

-diagnostic design optimized for HPCAT

  -static delay of 0.7 ns at 11.5 keV

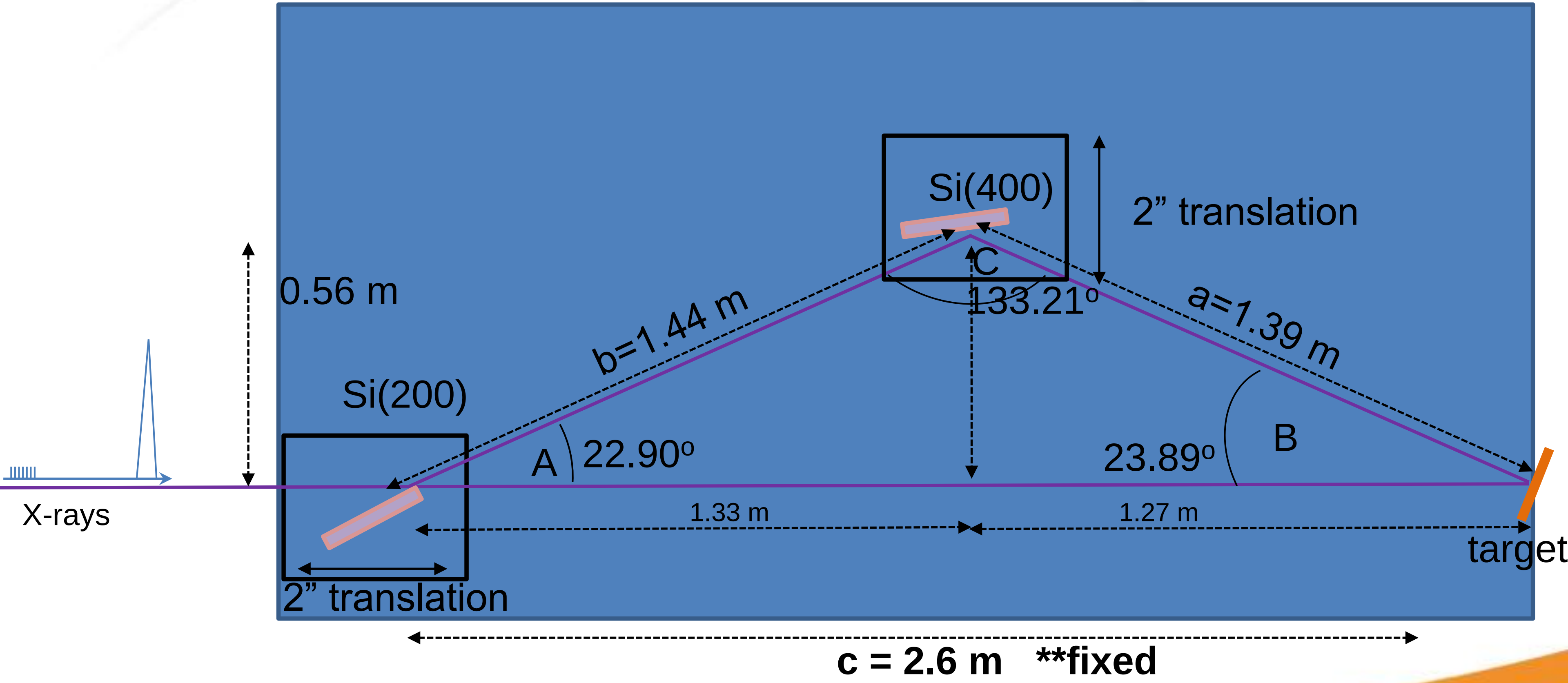
→ Beamtime completed July 2-8 at APS: HPCAT IDE

→ Preliminary results presented in this talk



Delay Line design 2018

Schematic: For wavelength: 11.5 keV; 0.7 ns delay



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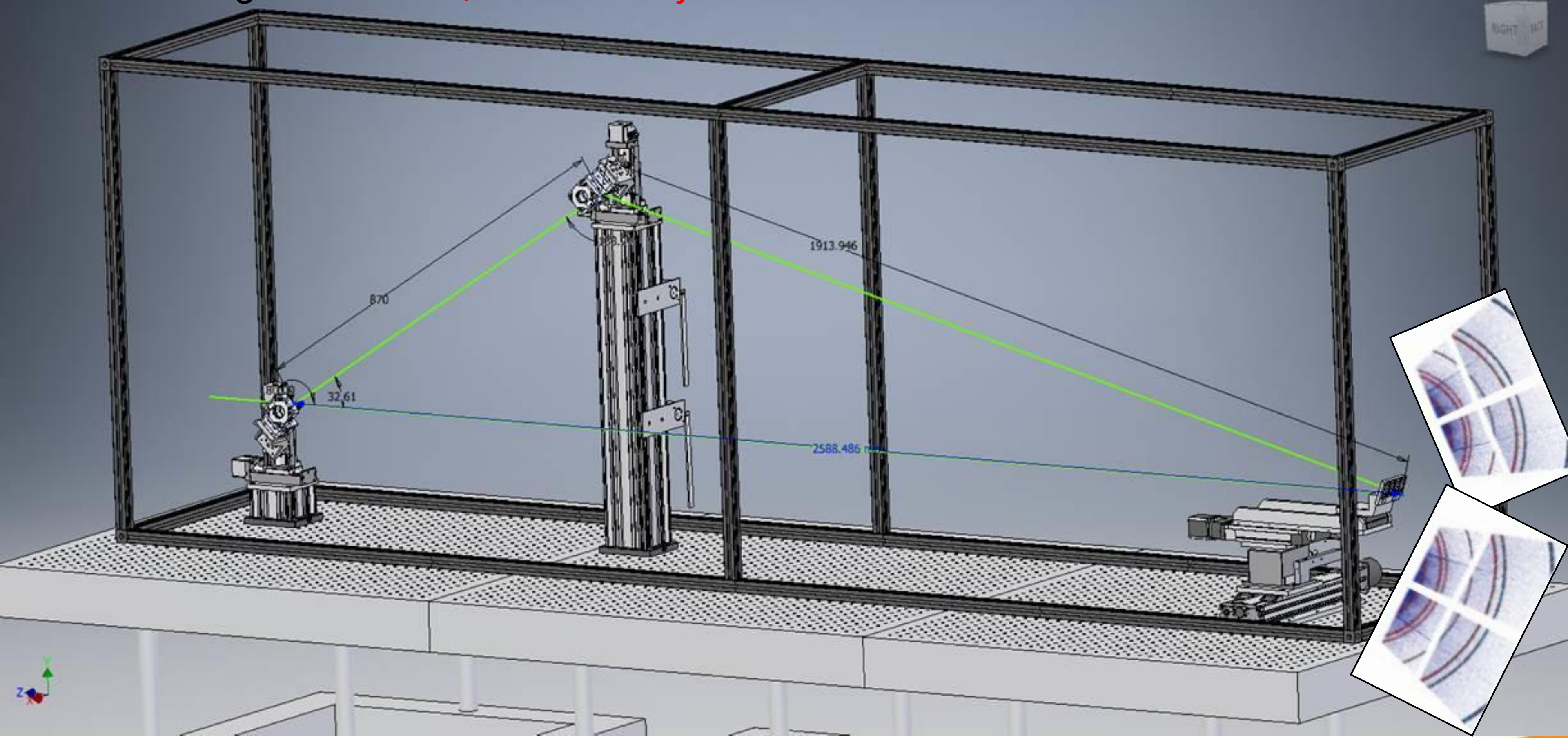
Delay Line design 2018

For wavelength: 11.5 keV; 0.7 ns delay



Delay Line construction 2018

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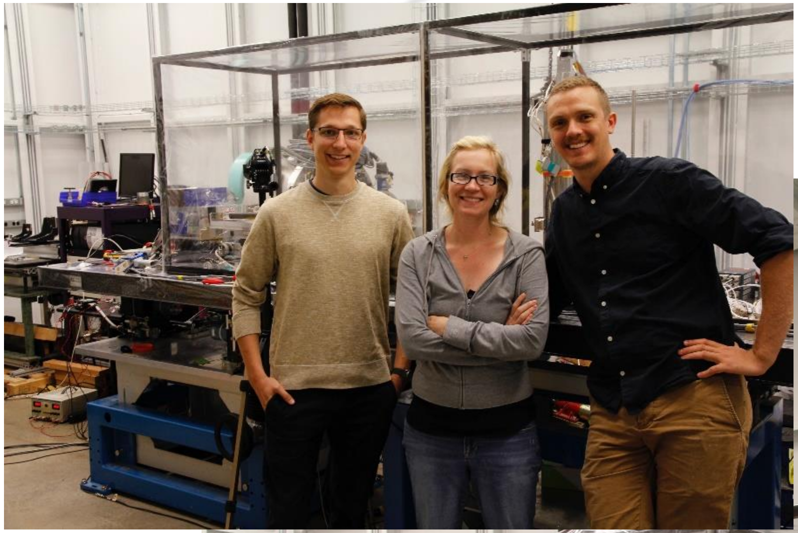
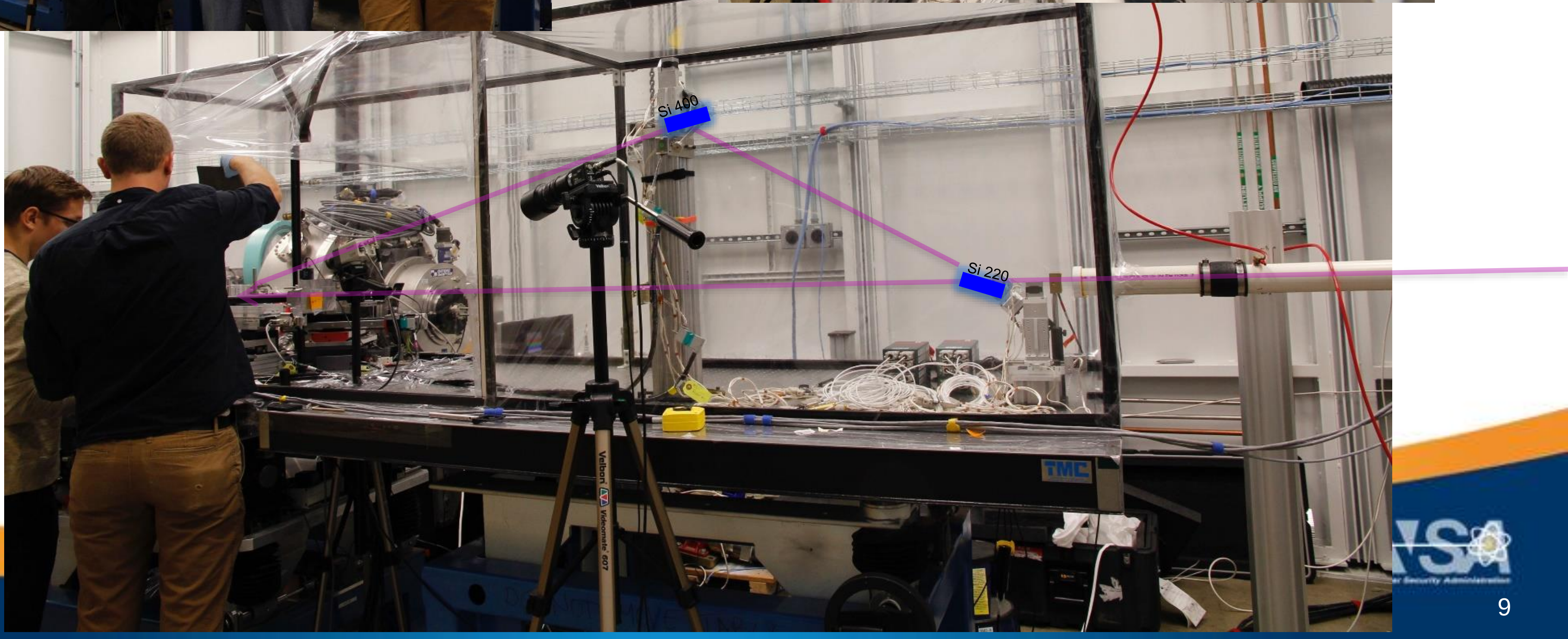
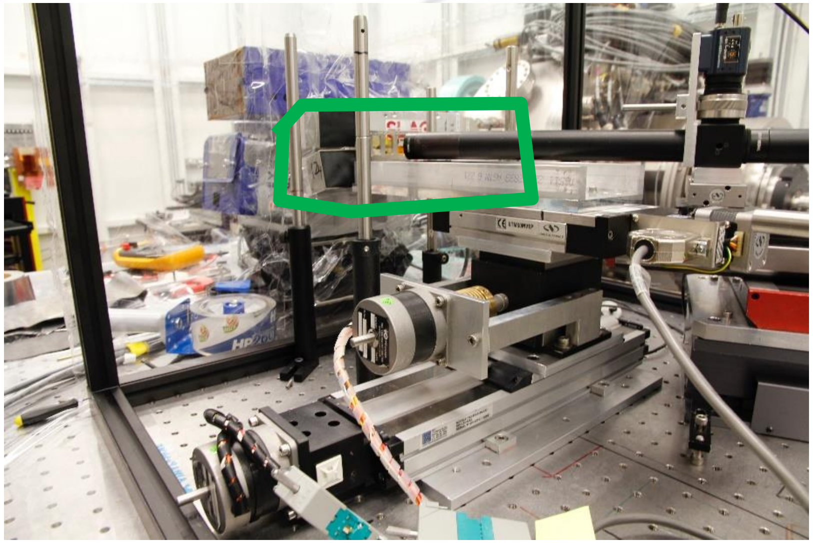




Detectors



CSPADs (LCLS)

-charge integrated detector
-smaller active area
-moderate framing rate (shortest at 2.8 us), good signal to noise

Pilatus detectors (APS)

-counting detector
-larger active area
-fast framing rate (shortest at 1.0 us) but poor signal to noise

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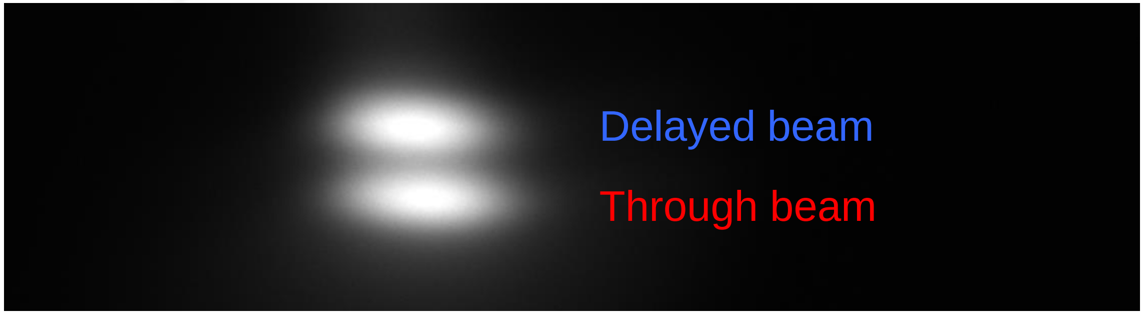
X-ray beam character

X-ray spots on a YAG screen



overlap achieved on a YAG screen

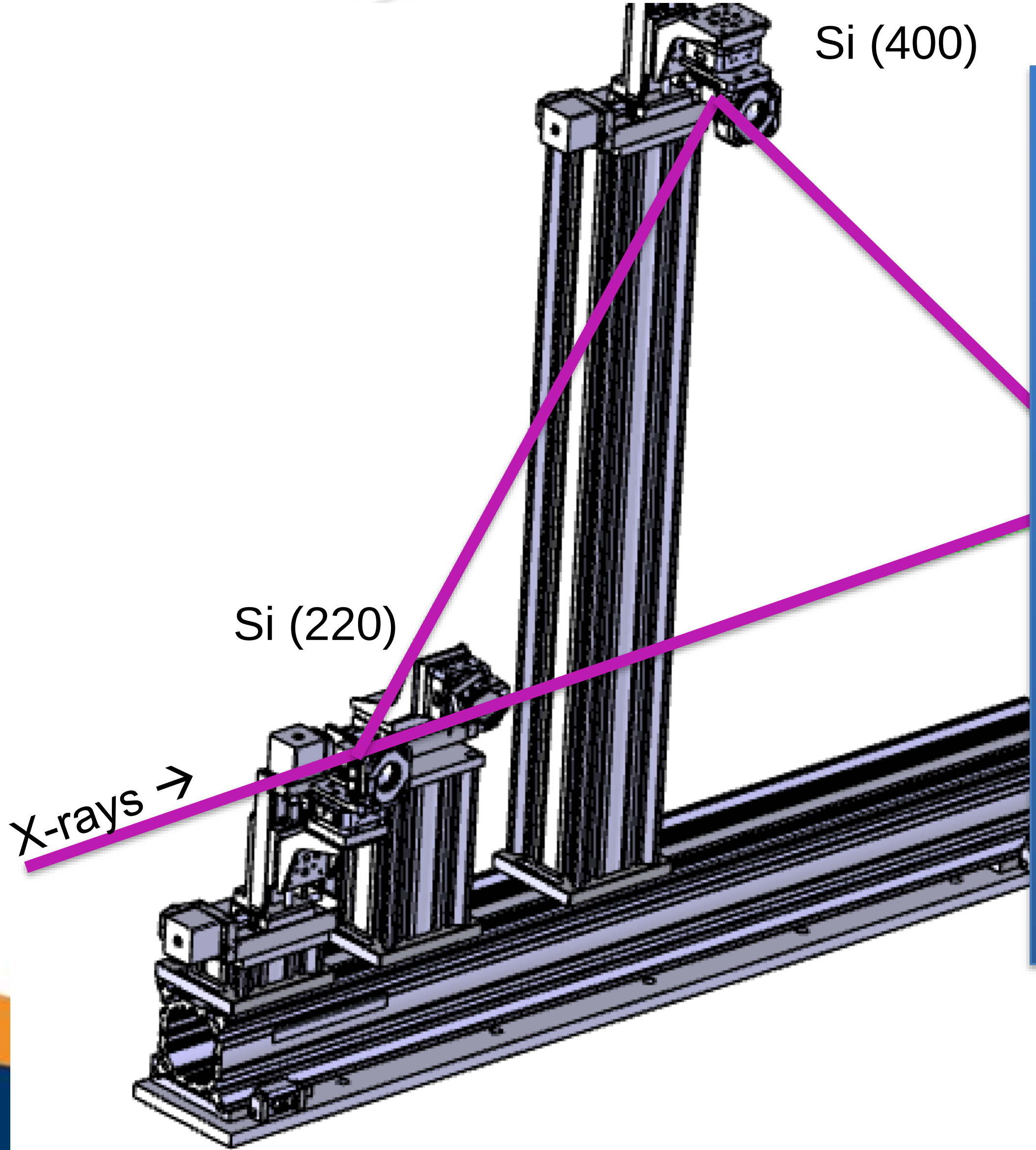
Photon count with hutch optimization (e.g., He max flow; 2 kapton windows) measured at the entrance to the enclosure:

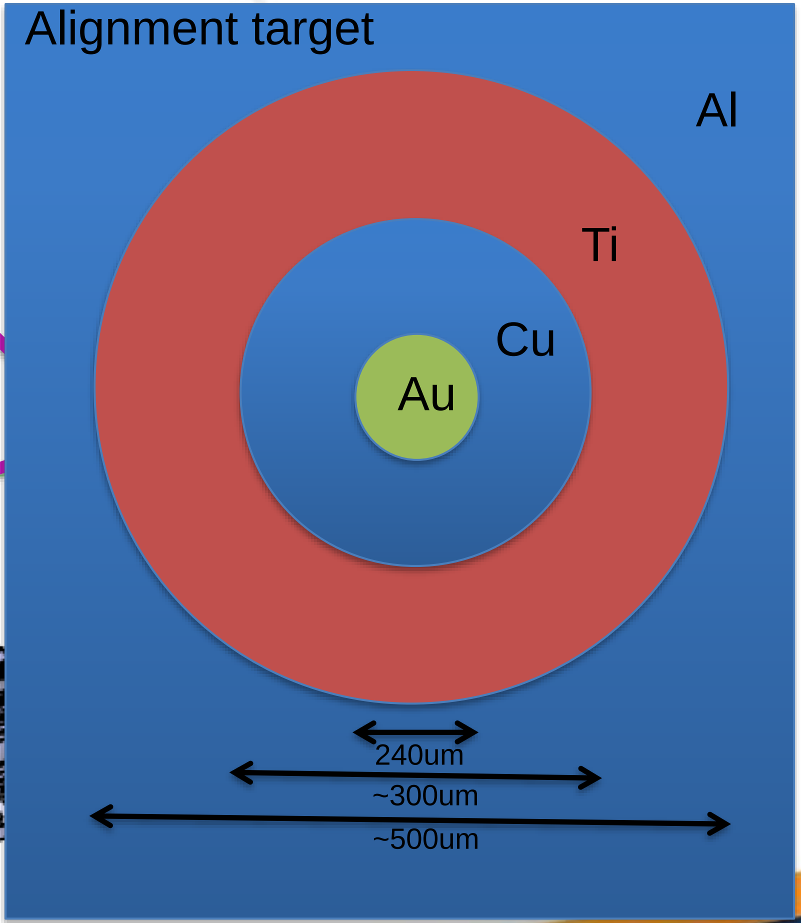
→ Diode reading = 351900 mA/V = 6.1×10^{12} ph/s

Other HPCAT-IDE specific photon parameters:

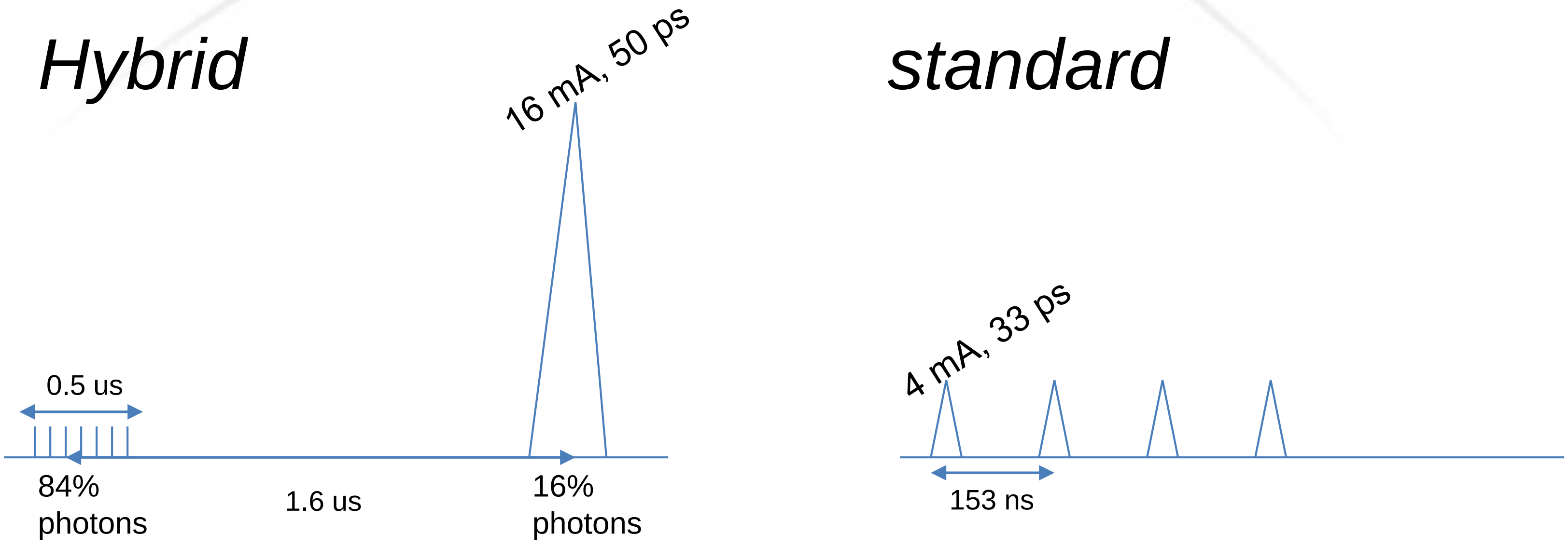
→ Before mono: 200 eV bw
→ 4-bounce Si mono gives 11.5 keV
→ Large KB focusing optics
→ Measured and modeled bandwidth: 1.2 eV bw

Spatial overlap procedure





Synchrotron modes of operation

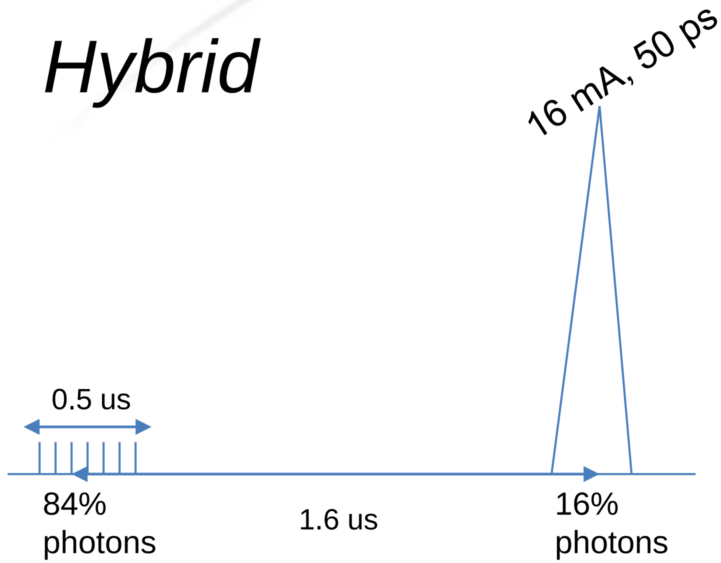


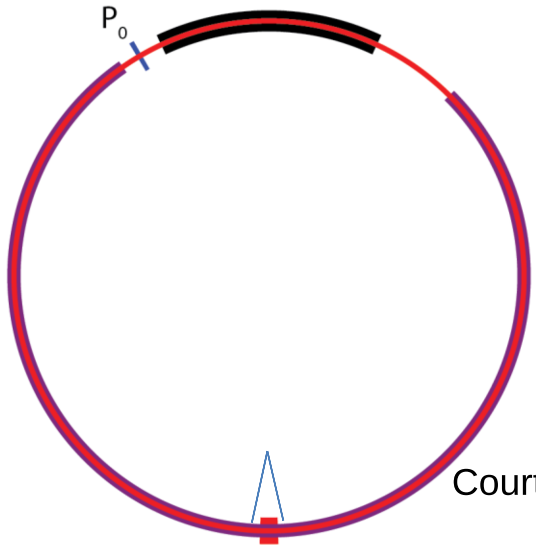
July 2018
Super pulse period = 3.6 us

Aug. 2017
10 usec*2e11ph/s = 2e6 photons to see XRD

Synchrotron timing with CSPAD

Hybrid



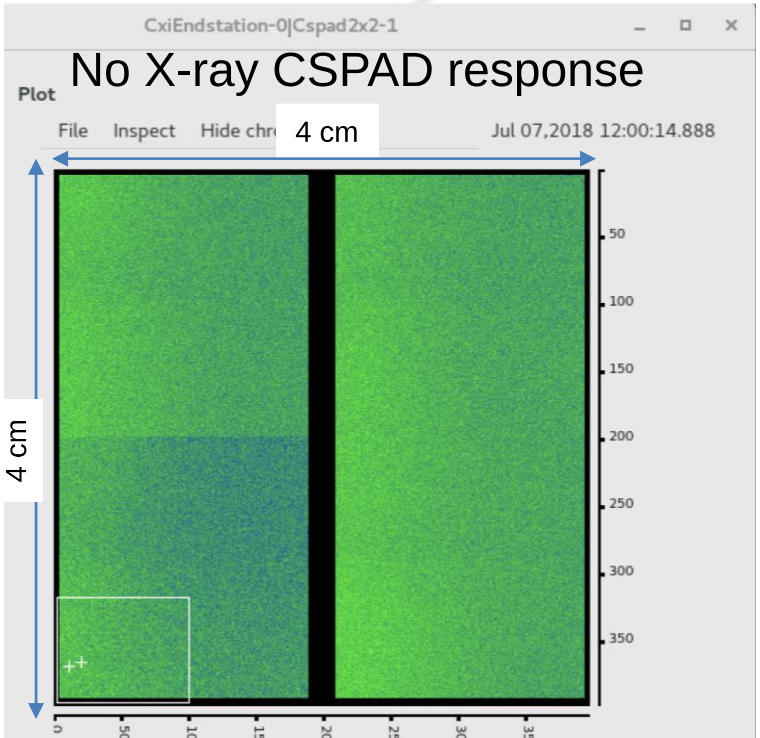


Courtesy J. Lazarz

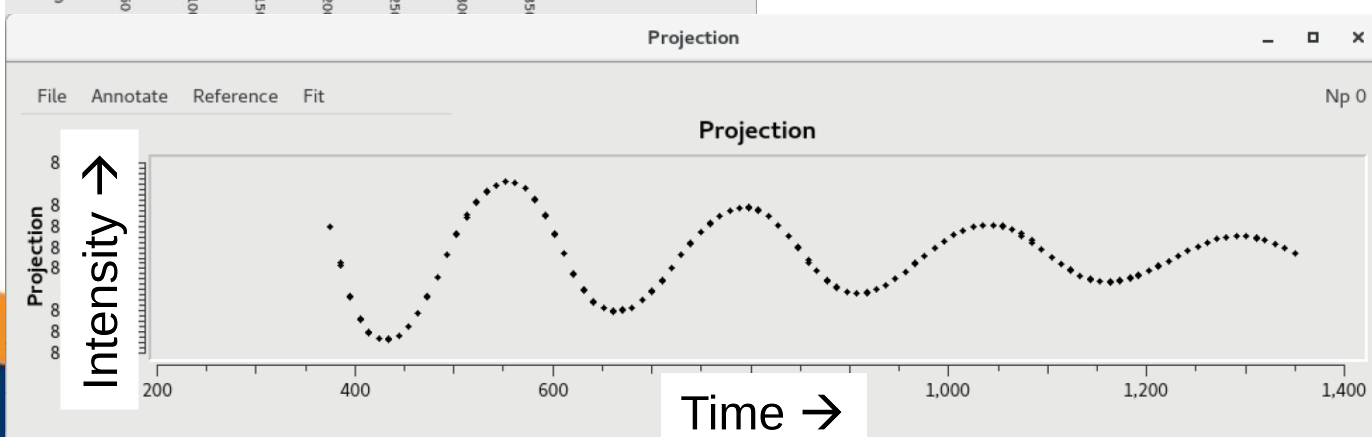
July 2018
Super pulse period = 3.6 us

-Exposure time of cspad limited to 2.8 us
-increment this 2.8 us-gate time around the ring

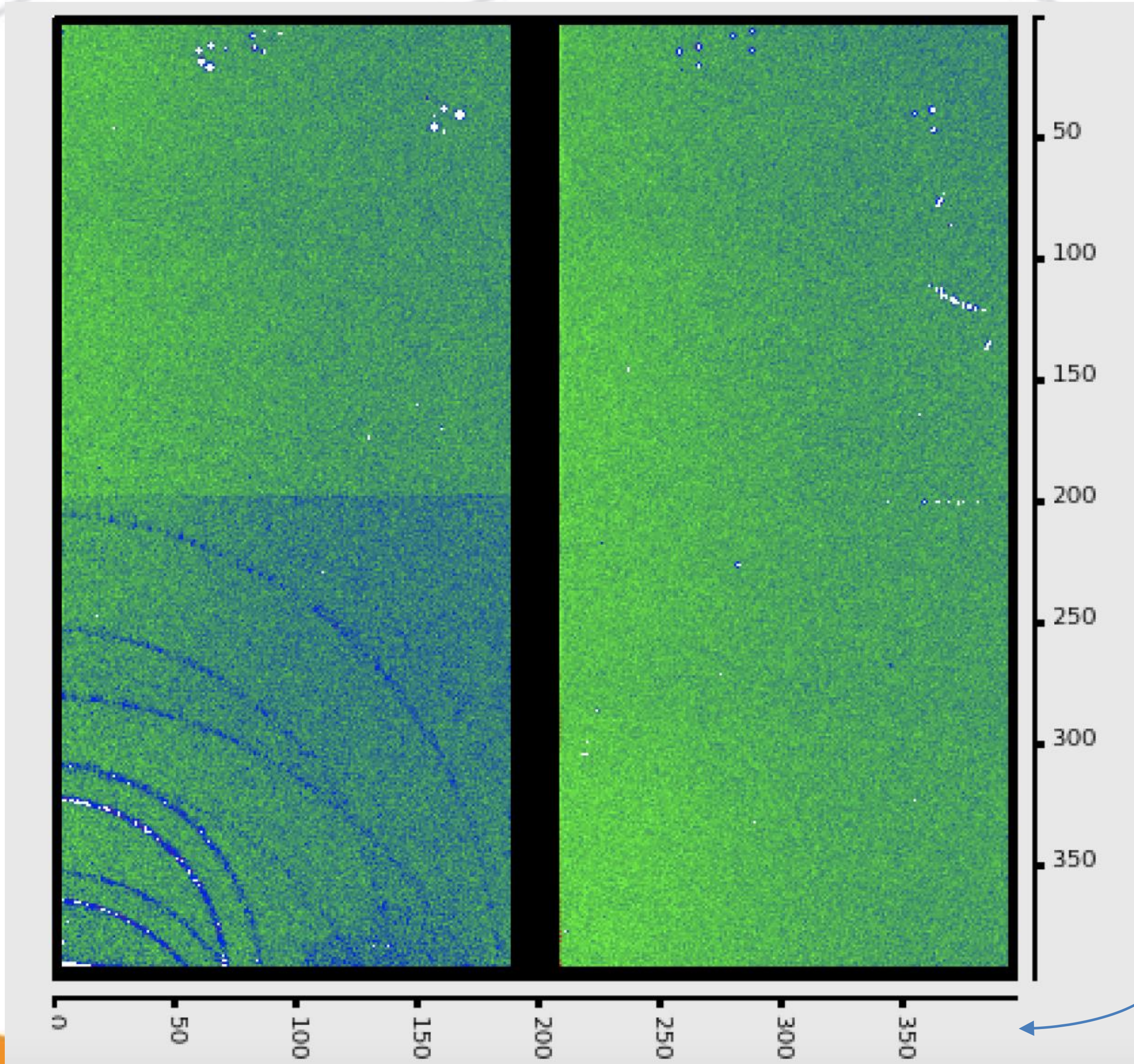
CSPAD results



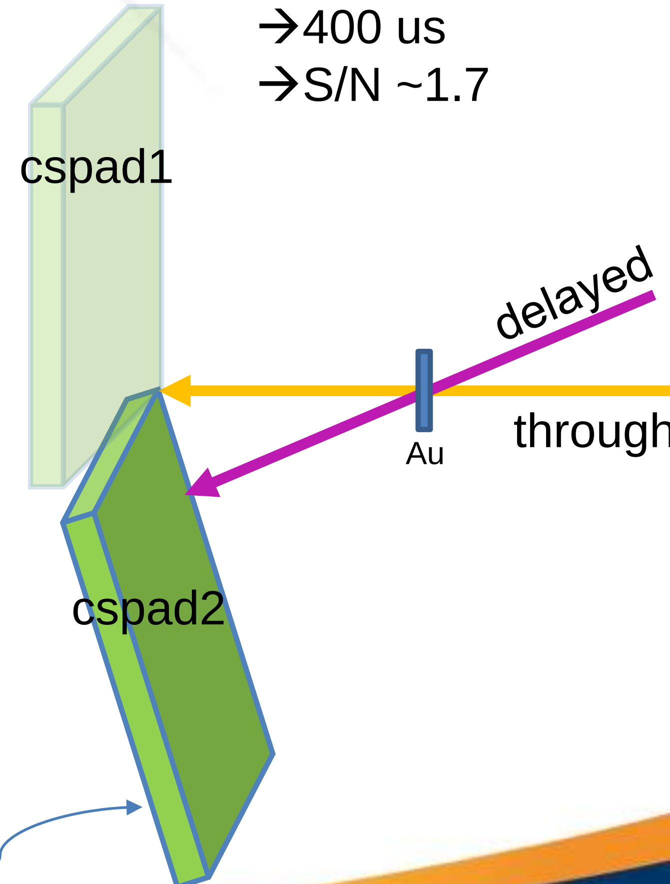
-charge acquires signal over a specified time
-allows one to read multiple photons of possibly different energies and combine photons across pixels.
-this is especially suited for discrete pulses of signal and weak signal



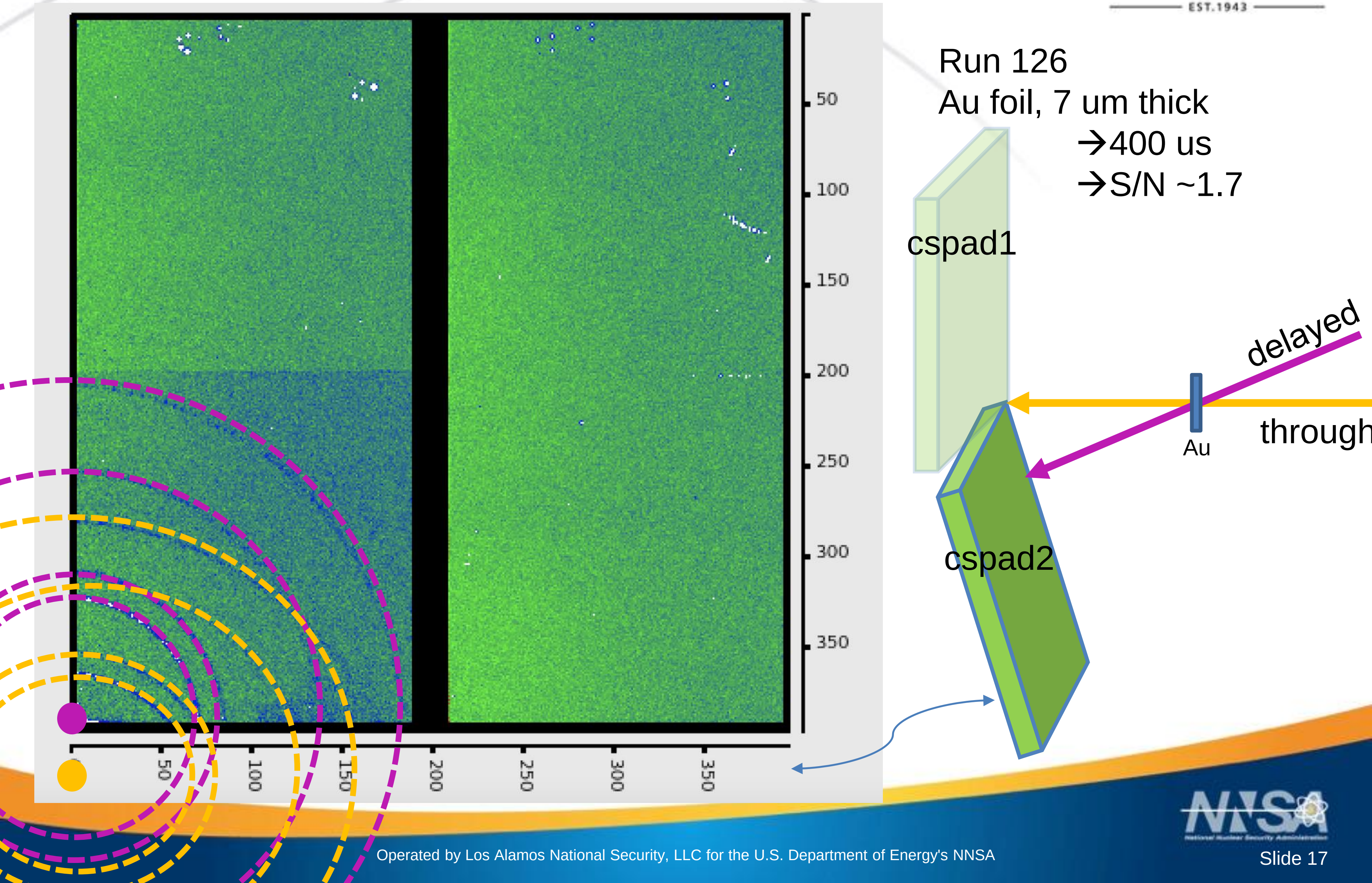
CSPAD results



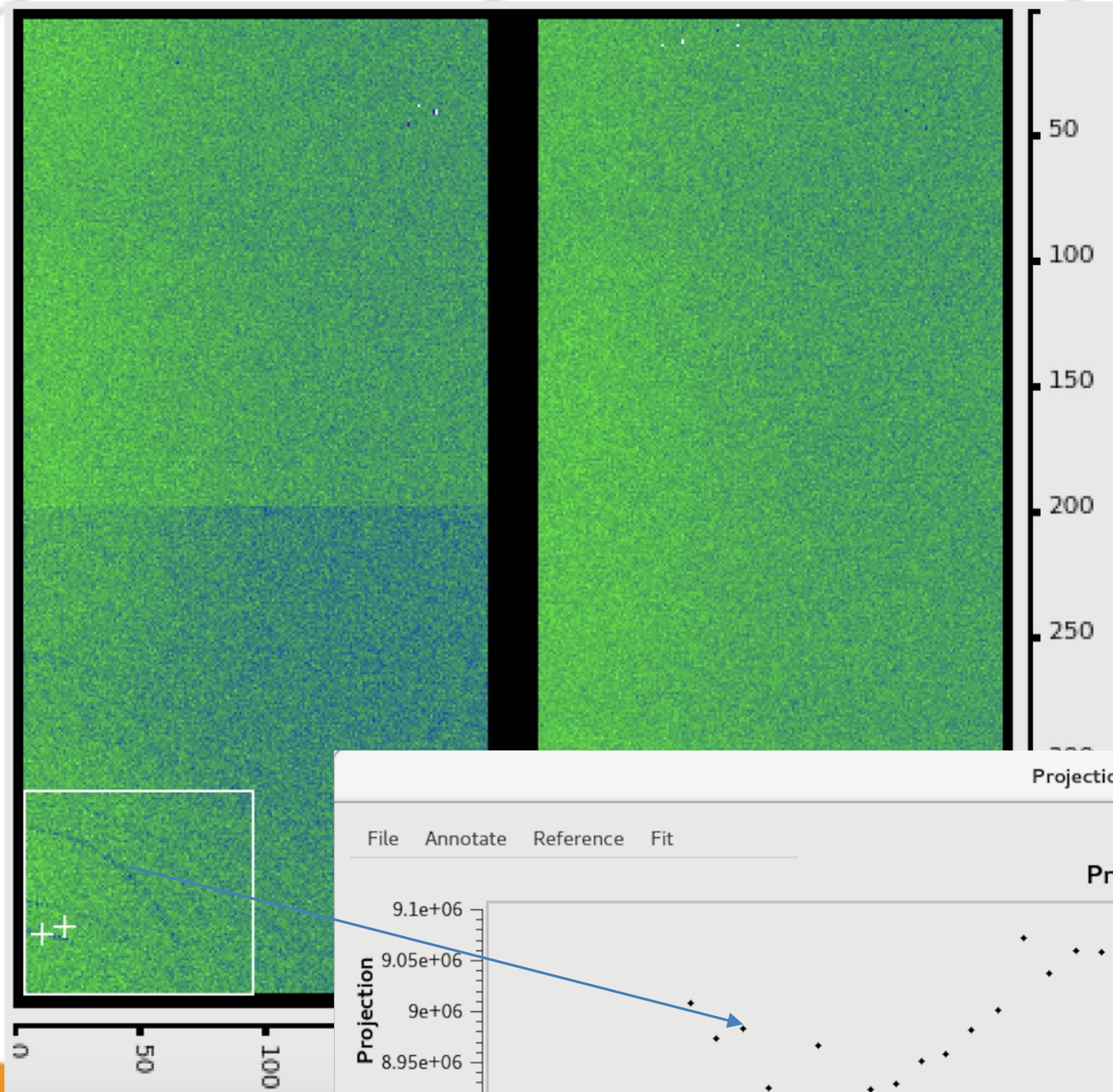
Run 126
Au foil, 7 um thick
→400 us
→S/N ~1.7



CSPAD results

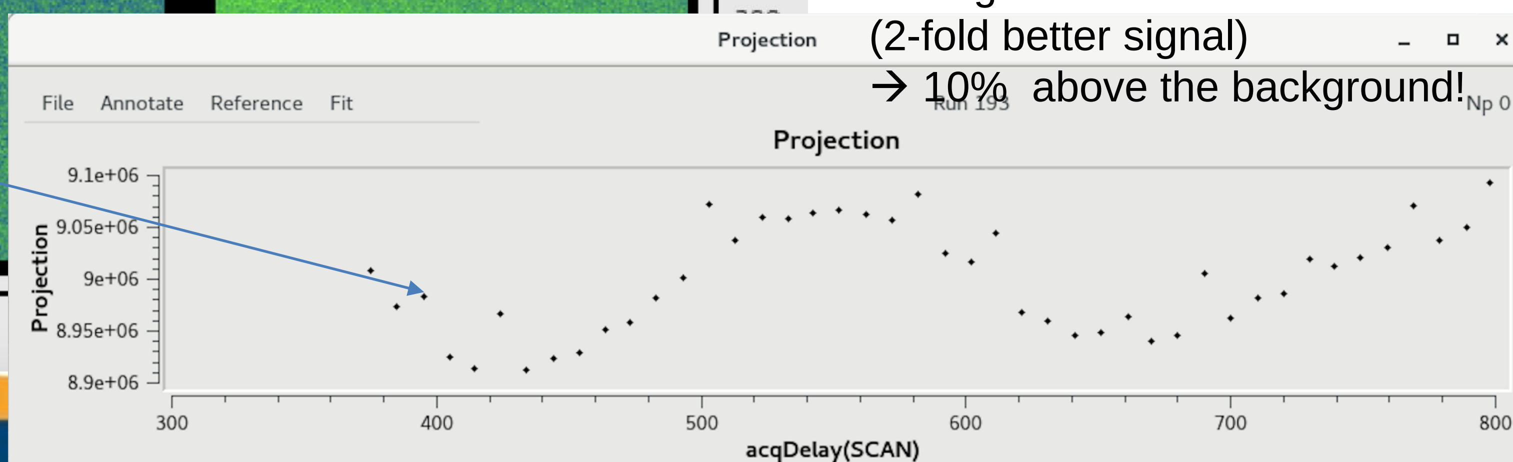


CSPAD results



Script test8
Au foil, 7 um thick
→2.8 us
→this is the gating limit of the CSPADs
→isolated a 50ps superpulse
→S/N ~1.05 in the through and delayed beam

Additional improvements:
-background subtraction scheme (2-fold better signal)
→ 10% above the background!



Timescales suitable for dynamic driver

@ APS we have now demonstrated:
-we can isolate an APS superpulse (50 ps pulse width) and still resolve signal 10% above background in a through and delayed beam

Dynamic experiments we can now pursue at HPCAT
if we are detector-gate limited
→Split-Hopkinson Bar (8 us for a shock transit so useful science could be done with 1-2.8 us gates)
If we obtain fast X-ray shutters
→Gas gun drivers (1-1.25 us shock transit so useful science could be done with 0.25-0.5 us time-slices)

Dynamic experiments we can now pursue at an XFEL
-sky's the limit – we will clearly have enough flux

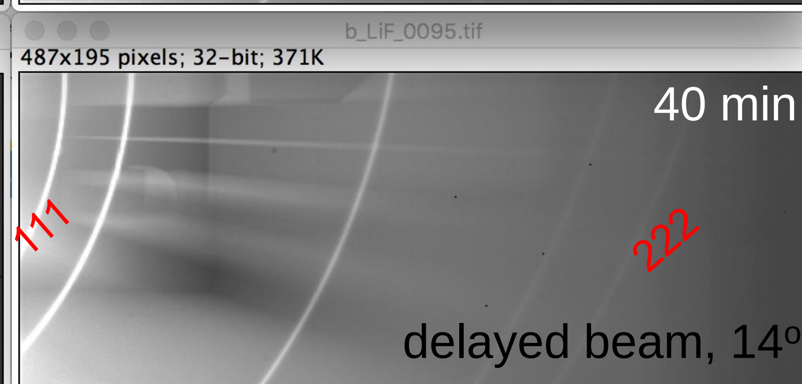
Pilatus detector results

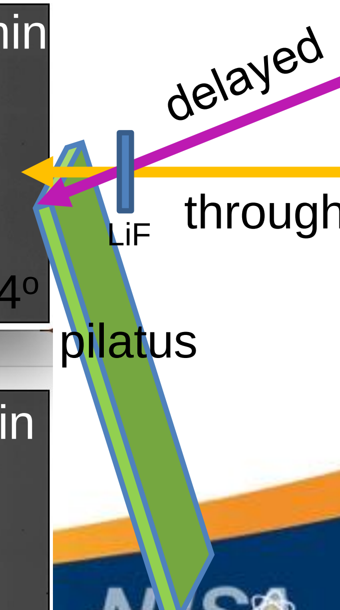
-threshold on the amount of energy in a pixel and reports back (i.e., stops collecting)
-above this threshold it resets and waits for the next photon
- Counting rate/pixel: > 2 x 10^6 ph/sec

Optimized for strain decoupling tests on LiF

LiF	cubic	Ang		Ang^-1	deg
Wyckoff, 1963	int	d-spc	hkl	Q	2theta for FEL
card 85-237	77	2.3194	111	2.70897012	26.87757994
	100	2.0087	200	3.12798591	31.13273471
	44	1.4203	220	4.42384377	44.6088857
	10	1.2113	311	5.18714217	52.84825981
	11	1.1597	222	5.41794025	55.39622319

Powdered samples:
-milled for 40, 20, 10, 5, 2.5, 1.2 min





Project Status at the end of FY

-delay line has been fully tested and exercised

-quantitative analysis/optimization of XRD ongoing (background subtraction; tiff conversion; binning tests)

-manuscript preparation & LDRD report

-poised to conduct a dynamic experiment on a 3rd or 4th generation lightsource:

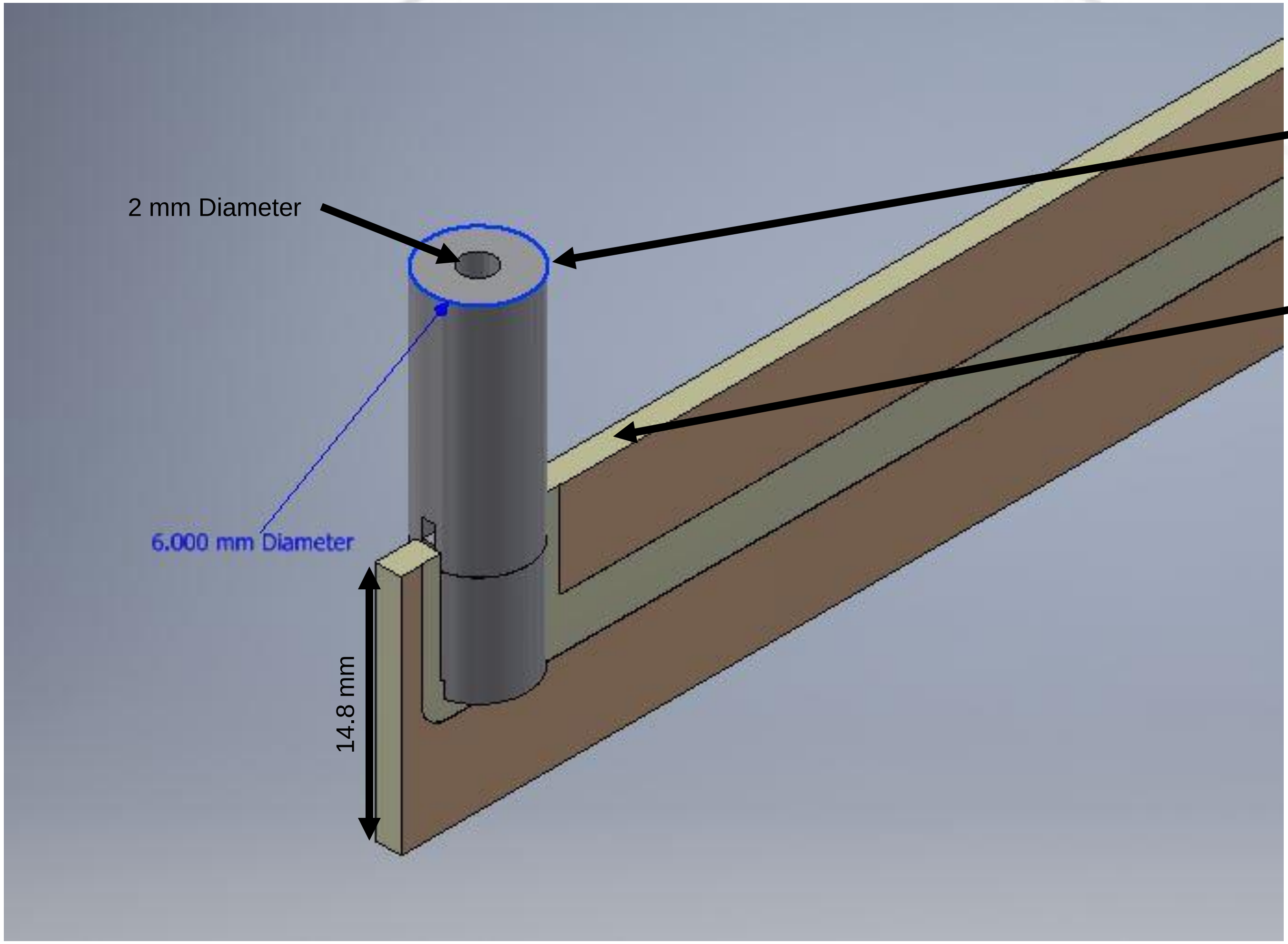
@ APS: SHB dynamic compression experiment for next beamtime

@ LCLS/ExFEL: laser-driven shock compression experiment will be proposed again for Run 18

Future work

- APS, HPCAT: due 10-26-18 (Run 2019-1)
  - -Add focusing optics upstream (e.g., Be CRLs)
  - -Add beamstop
  - -Better shielding to mitigate scatter
  - -Replace large volume enclosure with tubing
  - -Ion chamber to monitor X-ray flux *in situ*
  - -use next generation CSPAD (ePix 10k, JungFrau)
- LCLS, MEC: due ~Sept. 2019 (Run 18)
  - -multi-branch delay line + compatibility with MEC chamber
  - -gated detector + multi-pulse mode from LCLS

Diode Beamstop

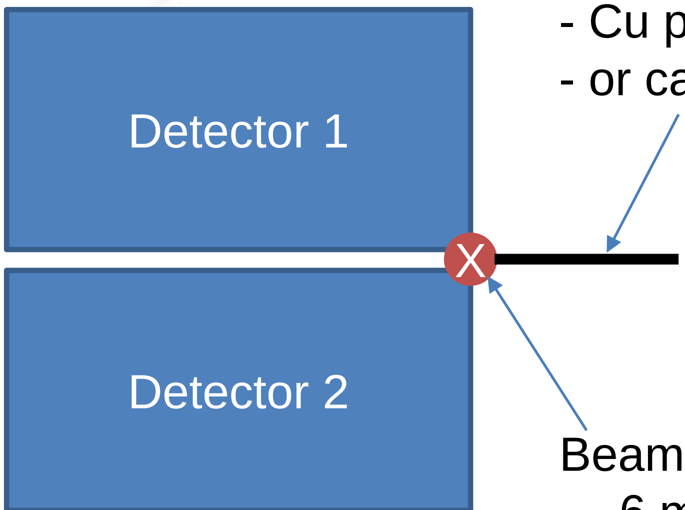


Machinable W
- Diode inside

Cu plated G-10 Fiberglass
- Circuit traces milled out

Courtesy A. Golder

Potential Configuration



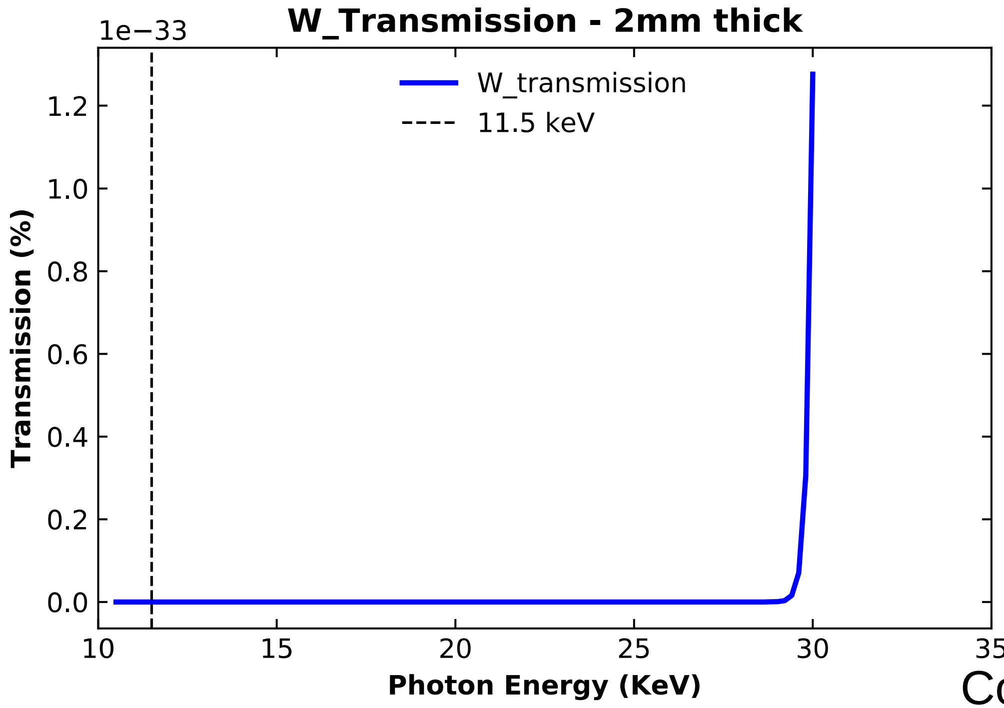
Beamstop support
- Cu plated G-10 fiberglass (w/ diode option)
- or carbon fiber rod

Beamstop
- 6 mm diameter
- W cylinder
    - W rod ~$60 (McMaster)

Courtesy J. Lazarz

Plain Beamstop

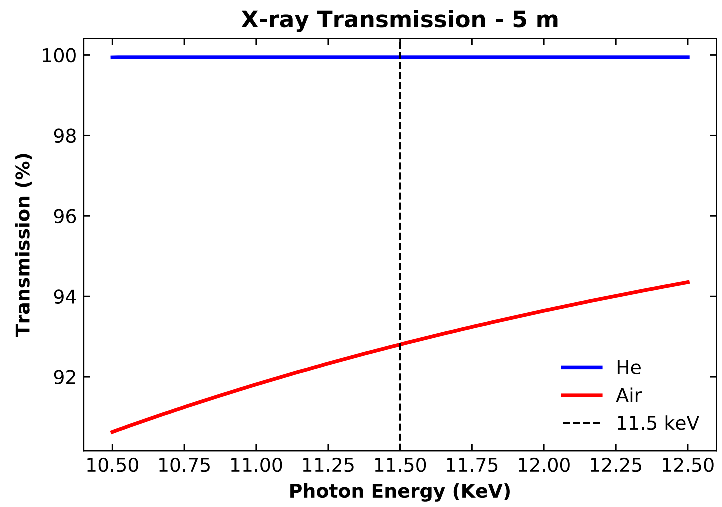
- 2 mm of W will work well

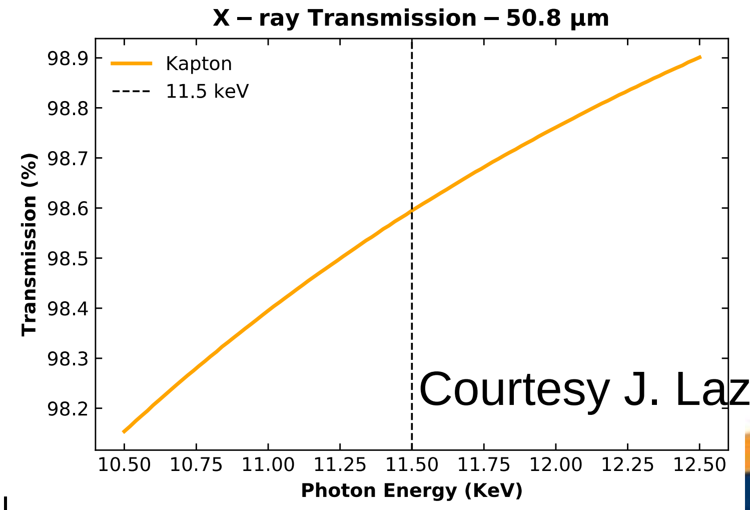


Courtesy J. Lazarz

The importance of He flight paths

- 11.5 keV X-ray transmission is terrible through 5m of air; better through He.
- Transmission:
  - He – 99.941%
  - Air – 92.803%
  - Kapton – 98.595%
- After 5 Kapton windows lose ~7% transmission.

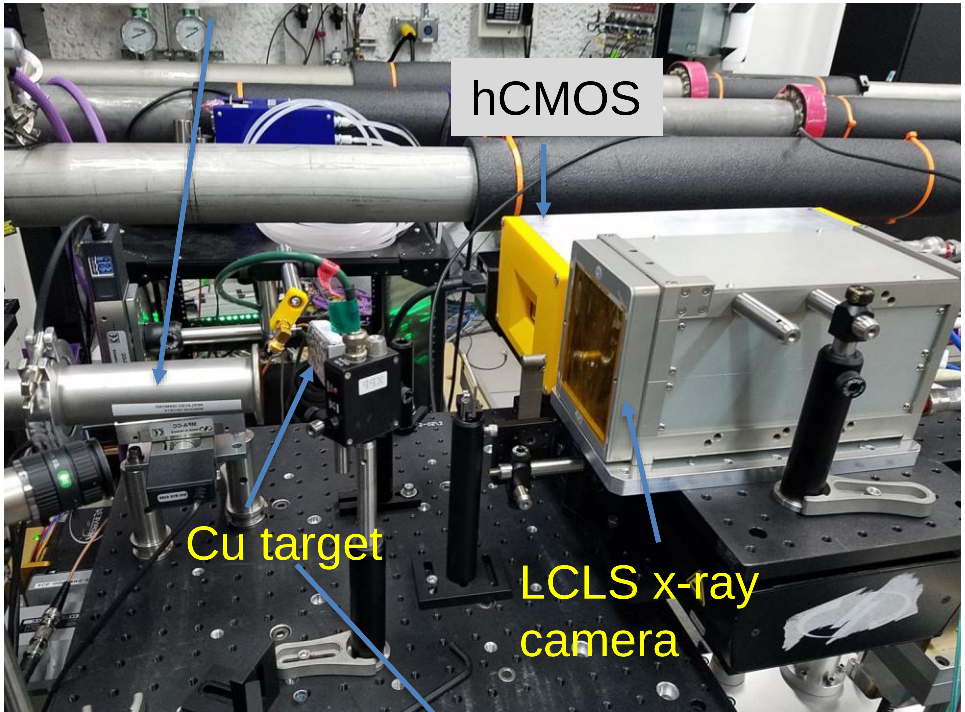




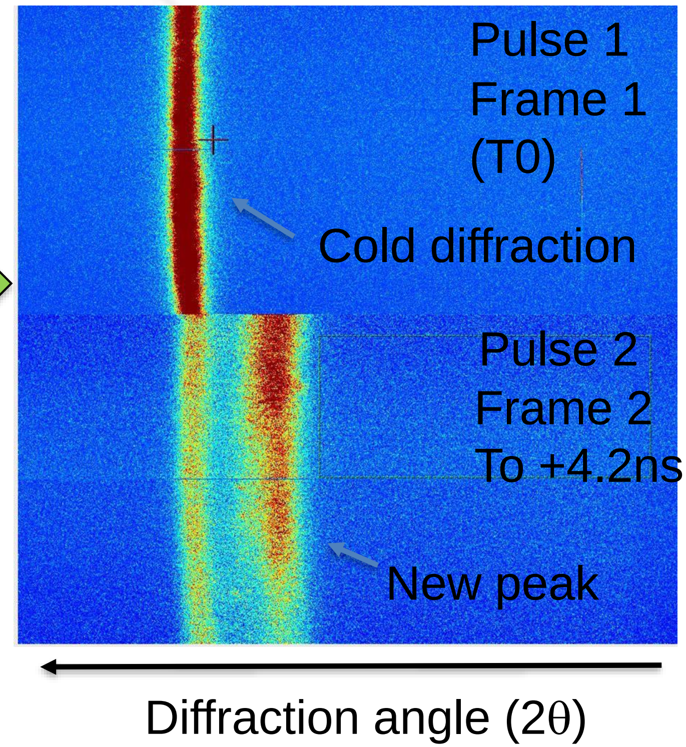
Courtesy J. Lazarz

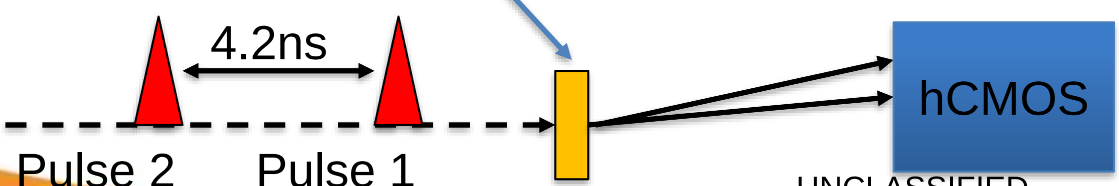
hCMOS camera developed by SNL/LLNL has been tested* using LCLS femtosecond x-ray pulses: linearity, gate profile, QE…

LCLS : Two x-ray pulses, 7.2keV, 4.2ns apart



hCMOS Images





- Frame 1 = cold diffraction Cu (111)
- Frame 2 = new peak thermally expanded Cu (111)**

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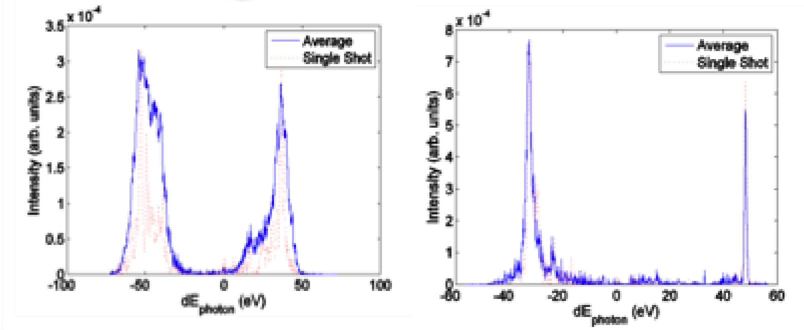
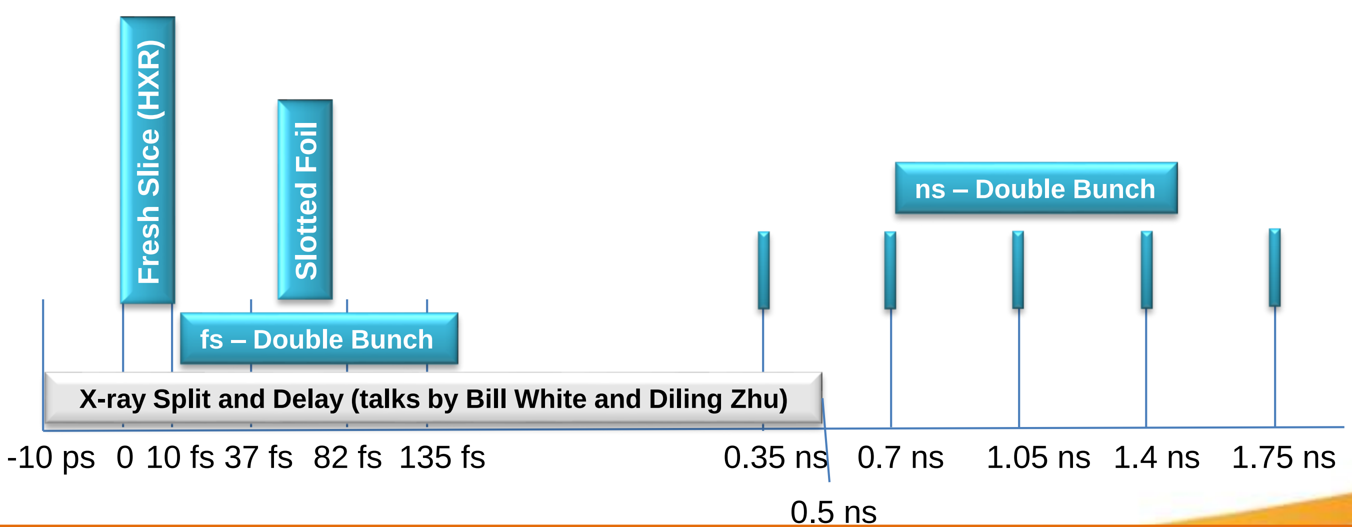
* Experiment led by P. Hart (SLAC), ** analysis by Arianna Gleason (LANL/SLAC)

Development of new dual-pulse / dual-color modes

Los Alamos NATIONAL LABORATORY EST.1943

- Double Slotted Foil
- Split Undulator
- Injector Laser Pulse Splitting
- Multiple Laser Pulses at Cathode (dual lasers)
- Fresh Slice Technique





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Development continues for Multi-bunch (>2) Operation